Determination of Moduli of Elasticity of Latewood and Transition Latewood of Japanese Cedar by Using Digital Image Analysis

Tzu-Yu Kuo†*, Wei-Chung Wang†, Huai-Syuan Huang‡, and Jean-Shang Wang⸸

Department of Power Mechanical Engineering, National Tsing Hua University, Taiwan, Republic of China,
†* asmit.com@msa.hinet.net
† wcwang@pme.nthu.edu.tw
Department of Industrial Engineering and Management, Da-Yeh University, Taiwan, Republic of China,
‡ a0970317809@gmail.com
⸸ jswang01@mail.dyu.edu.tw

Wood is a kind of composite material found in nature. The latewood (LW), transition latewood (TL), and earlywood (EW) as layers of composites are observed in a tree ring and are varied from species to species and from site to site. To understand the stiffness of wood structures, it is necessary to accurately determine the modulus of elasticity (MOE) of the timber. However, as a typical example, the MOE of Japanese cedar (*Cryptomeria japonica*) ranges from 2 to 12 GPa [1-3]. Therefore, it is difficult to select an appropriate value of MOE to be used in computational mechanics for studying wood and wood-based products. In this paper, X-ray densitometry (XrD) technique, tracheidogram method, and digital image analysis (DIA) were employed to determine the boundary of LW, TL and EW proportion of Japanese Cedar popularly found in both Taiwan and Japan. The determination of MOEs of LW, TL, and EW were based on the correlation between MOEs and density.

In this paper, Japanese cedar was used as the specimen material. The wood log was cut across over the pith into wood lumber pieces and then air dried for more than one year before the experiments were performed. XrD specimens with a thickness of 2 mm were cut from the top of the lumber. All samples were maintained at 25°C and controlled at 60% relative humidity for more than a week. A commercially available X-ray densitometer, QMS QTRS-01X Tree Ring Scanner [4] was used to measure the density profiles of the XrD specimens.

The tracheidogram method uses curves of cell size variations in radial files of xylem cells [5]. To observe variations of tracheid dimensions along a tree ring, the digital image of cell walls was measured by using an optical microscope at 100X magnification. Because of the limitation of the field of view, an image stitching technique must be used on the obtained full image. A commercially available software, MATLAB [6], was used in this paper to measure the lumen radial diameter and the radial wall thickness. According to the Mork's definition (MD) [7], the boundary of LW, TL, and EW were defined as follows: MD $\leq$ 0.5, EW; 0.5 $<$ MC $<$ 1, TL; MC $\geq$ 1, LW.

The DIA technique proposed in [8] is based on the optical properties reflected by the light on the specimen surface. The gray level was determined from the light reflected by the radial cross-sectional surface. The dark and light fringes represent a lower and higher gray level, respectively. It should be noted that the dark and light fringes correspond to the higher and lower density of the density data obtained from XrD technique, respectively.

Based on the resemblance between the density profile, MD curves, and reverse gray-level profile, the use of DIA was proposed in this paper to determine the boundary of LW, TL, and EW portions. Finally, the values of MOE of LW, TL, and EW were determined by using the boundary of LW, TL, and EW based on the correlation between MOE and density.

References

[1] K. Yamashita, Y. Hirakawa, S. Saito, H. Nakatani, and M. Ikeda: Bow variation in kiln-dried boxed-heart square timber of sugi (Cryptomeria japonica) cultivars, *Journal of Wood Science*, Vol. 57(5), pp. 363-370, 2011.
[2] K. Yamashita, Y. Hirakawa, H. Nakatani, and M. Ikeda: Longitudinal shrinkage variations within trees of sugi (Cryptomeria japonica) cultivars, *Journal of Wood Science*, Vol. 55(1), pp. 1-7, 2009.
[3] J. Zhou, and J. Shen: Ellipse detection and phase demodulation for wood grain orientation measurement based on the tracheid effect, *Optics and Lasers in Engineering,* Vol. 39(1), pp. 73-89, 2003.
[4] Quintek Measurement Systems, Website: www.qms-density.com/, Accessed: Jan. 2019.
[5] E. R. Cook, and L. A. Kairiukstis: M*ethods of dendrochronology: applications in the environmental sciences*, Springer Science & Business Media, 1989.
[6] MathWorks - Makers of MATLAB and Simulink, Website: https://www.mathworks.com/, Accessed: Jan. 2019.
[7] E. Mork: Der Qualitat des Fichenholzes unter besonderer Rucksichtnahme auf Shief - und Papierholz, P*apierfabrikant (Der Papier Fabrikant*), Vol. 26, pp. 741-747, 1928.
[8] T. Y. Kuo, and W. C. Wang: Determination of effective modulus of elasticity of wood from proportion of latewood, *World Conference on Timber Engineering 2016 (WCTE 2016*), Vienna, Austria, 2016.

 ISBN: 978-91-88898-64-7